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Comparison of aerosol optical thickness measurements by MODIS, AERONET sun photometers, and Forest Service handheld sun photometers in southern Africa during the SAFARI 2000 campaign

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The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the NASA Terra satellite has been used to monitor aerosol optical thickness (AOT, τ) daily at $10\,\text{km} \times 10\,\text{km}$ resolution worldwide since August 2000. This information, together with the locations of active fires detected by the MODIS instrument, is essential for understanding the seasonal trends and interannual variability of fires and their impacts on air pollution, atmospheric chemistry, and global climate. We compared aerosol optical thickness derived from MODIS, five automated sun photometers of the Aerosol Robotic Network (AERONET), and 38 Forest Service (FS) handheld sun photometers in western Zambia from 20 August to 20 September 2000. Aerosol optical thicknesses derived from AERONET sun photometers and FS sun photometers were also compared in the same region between mid-June and late September 2000. Our objectives were to validate the AOT measurements by MODIS and to investigate the factors that affect AOT measurements. We demonstrated that in the regions of intense biomass burning, MODIS aerosol optical thickness was consistently 40–50% lower at 470, 550, and 660 nm compared with ground-based AOT measurements by automated and handheld sun photometers and airborne measurements by NASA Ames Airborne Tracking 14-channel Sunphotometers (AATS-14). The satellite look angles can influence the MODIS AOT values, with the actual MODIS AOT values being as much as 0.06 higher than model-calculated MODIS AOT values on the right edge of the MODIS scene. This phenomenon may be due to error in the assumed aerosol scattering phase function or surface directional properties. Density of vegetation cover can also affect MODIS measurements of aerosol optical thickness.

1. Introduction

Fires have been widely used in the tropics for deforestation, shifting cultivation, savannah burning, and energy use during the dry season. Vegetation fires produce trace gases and aerosol particles during the combustion process (Crutzen *et al.* 1979, Crutzen and Andreae 1990). These compounds and particles can significantly affect regional air quality, tropospheric and stratospheric chemistry, and global climate.

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Approximately 45% of the annual biomass burned in tropical countries occurs in the Northern Hemisphere and about 55% in the Southern Hemisphere (Hao and Liu 1994). In order to understand the impact of these fires on the regional and global environment, it is essential to systematically monitor spatial and temporal distribution of fires and associated trace gas and particulate emissions on a global scale. The Moderate Resolution Imaging Spectroradiometer on the NASA Terra and Aqua satellites, launched on 17 December 1999 and 4 May 2002, respectively, have been monitoring daily active fires and aerosol optical thickness worldwide (Kaufman *et al.* 2003). These measurements provide seasonal cycles, trends, and emissions from fires in various ecosystems.

Fire is the dominant source of atmospheric pollutants in the Southern Hemisphere. Most seasonal and interannual variability of carbon monoxide concentrations, measured at the NOAA Climate Monitoring and Diagnostics Laboratory stations in the Southern Hemisphere, can be attributed to biomass burning (Duncan *et al.* 2003). The Southern Hemisphere fire season usually starts near the equator in June, progresses southward, and ends near 30° S in October (Cahoon *et al.* 1992, Hao and Liu 1994, Justice *et al.* 1996, Barbosa *et al.* 1999, Dwyer *et al.* 2000). During the Southern African Regional Science Initiative (SAFARI) 2000 campaign, we conducted extensive ground-based measurements of aerosol optical thickness in western Zambia from mid-June to late September. Miombo woodland savannas and Dambo grassland savannas are the dominant vegetation in this region. Fires are numerous from May to October during the dry season. Few fires occur in the rainy season from November to April, with annual rainfall ranging from about 1400 mm in the north to about 700 mm in the south (Chipungu and Kunda 1994). There are few industries in western Zambia, except near Ndola; thus, fires are the principal source of atmospheric aerosols. This circumstance made this region suitable to study the properties of aerosols from biomass burning with limited interference from industrial aerosols.

4. Conclusion

We compared the measurements of aerosol optical thickness taken by MODIS, AERONET sun photometers, and Forest Service handheld sun photometers in western Zambia from mid-June to late September 2000. The AOT data collected by automatic and handheld sun photometers agree within the AOT range of 0.03–0.8 at 880/870 nm, 0.05–0.8 at corrected 680/670 nm, 0.2–2.0 at 530/500 nm, and 0.3–2.5 at 380/380 nm. The results indicate that handheld sun photometers are indeed reliable instruments to monitor aerosol optical thickness in regions with extensive biomass burning. The atmosphere was relatively homogeneous during the period of the experiments, so ground-based AOT measurements by AERONET and handheld sun photometers are representative over a $10\,\mathrm{km} \times 10\,\mathrm{km}$ area, which is the sample size of MODIS AOT. Comparisons between MODIS measurements and ground-based measurements showed that the MODIS values on aerosol optical thickness could be underestimated by about 40–50% at 470, 550, and 660 nm bands. Using lower values of single scattering albedo in the MODIS AOT retrieval algorithm may reduce the differences. The satellite look angles and land surface properties can affect MODIS measurements of AOT. The values of aerosol optical thickness may be overestimated by about +0.06 on the right edge of the MODIS scenes. However, spatial variability, look angle, and land surface characteristics are not sufficient to account for the MODIS AOT values to be 40–50% lower than the ground-based AOT measurements.